Optically Tiled Flat Panel Displays
A Feasibility Study

November 1992

PO Number MDA972-92-M-0007

Prepared by
Honeywell Systems & Research Center
10701 Lyndale Ave. S.
Bloomington, MN 55420

Submitted to
DARPA/ESTO
Attn: Dr. Marko Slusarczuk
3701 N. Fairfax Drive
Arlington, VA 22203-1714

Final Report

Bernard S. Fritz, Principal Investigator

J. Allen Cox, Program Manager

93-S-1039

Optically Tiled Flat Panel Displays
A Feasibility Study

November 1992

PO Number MDA972-92-M-0007

Prepared by
Honeywell Systems & Research Center
10701 Lyndale Ave. S.
Bloomington, MN 55420

Submitted to
DARPA/ESTO
Attn: Dr. Marko Slusarczuk
3701 N. Fairfax Drive
Arlington, VA 22203-1714

Final Report

Bernard S. Fritz, Principal Investigator

J. Allen Cox, Program Manager

Optically Tiled Falt Panel Displays
A Feasibility Study

ABSTRACT

This report presents the results of a study examining the feasibility of micro-optic arrays to eliminate the seams between tiling modules making up a large flat panel display. The individual modules consist of commercially-available liquid crystal displays (LCD). We have found that tiling seams can be removed with micro-optic arrays but only by compromising other important display attributes, most notably display luminance and spectral bandwidth. The assumed module edge gap of 17.5 mm is the dominant parameter limiting performance, and this gap must be less than ~1 - 10 mm in order to have acceptable performance with existing backlights and LCD modules.

1. INTRODUCTION

It is commonly believed that the most practical approach to achieve large (~40 inch diagonal), direct-view, flat-panel displays is by tiling together a mosiac of smaller flat-panel modules. This approach has the advantages of higher yield producibility, low voltage operation, low weight, and low profile form factor. However, since each flat-panel module has some finite nonactive region around its periphery, such a tiling procedure results in seams or gaps between the individual modules. The effects of seams and other tiling artifacts on display quality have been discussed from the psychophysical viewpoint in a recent paper by Alphonse and Lubin[1]. They showed that the threshold detection angle of a dark seam is approximately 3.5 arcseconds. They also examined the required threshold for luminance variability across tiles, and they found that the threshold was about 5 percent at close distance (a few tile widths), 1-2 percent for normal viewing distance, and 0.25-0.5 percent around the distance of peak sensitivity of the eye (~3-5 cy/deg).

Removal of tiling seams by optical means is not new. Recently, Abileah and Yaniv[2,3] of Optical Imanging Systems, Inc have proposed the use of either fiberoptic or microchannel faceplates to solve this problem. The faceplates must be tapered to provide the correct magnification. Abileah and Yaniv have shown that the display system loses ~20 percent in resolution and 60-80 percent in transmission. Currently, tapered fiberoptic faceplates are available only in glass, and as such there is a significant weight penalty associated with this approach.

The use of diffractive spatiial filters has also been discussed recently by both Kelly[4] and Dolgoff[5] In this case, however, the intermediate diffractive element acts solely to filter out high spatial frequencies arisng from features within the individual pixel itself rather than between modules. Moreover, because the optical filtering is performed in the Fourier domain, this approach is really only appropiate for projection displays.

In this study, a preliminary effort was made to look at the use of micro-optic arrays to allow remapping of individual standard ("off-the-shelf") LCD modules to a larger size while effectively removing the dead zone gaps between adjacent displays, as pictured in Figure 1. The guidelines for this effort were that the display thickness and weight were critical parameters, with the ideal solution being one of a large tiled display, made up of the individual displays, that could be mounted on the bulkhead of an aircraft[6].

2. TECHNICAL ANALYSIS

The use of micro-optic arrays with standard black and white liquid crystal display (LCD) modules was examined. The main concept consisted of augmenting off-the-shelf LCD modules with micro-optics to allow tiiing the modules together. The parameters associated with standard LCD modules were provided by Jan Bernkopf of Magnascreen Corporation and are shown in Figure 2a and 2b.

Two design approaches were examined to allow tiling of standard LCD modules. In the first approach, we use micro-optics only after the LCD module, allowing no modification of the light box illumination system. The second approach allowed placing micro-optics both before the LCD module (after the illumination light box) and after the LCD module.

The first logical position of a micro-optic array would be to place it after the LCD module and use it to reimage the LCD active areas onto a diffusing screen with the appropriate magnification. Figure 3 shows this approach for the central five LC pixels and single bundle of rays leaving each pixel. The microlens array would be placed next to the cover glass polarizer to remap the LC pixels onto a diffusion screen. The closer the microlens is to the LC pixel the more light it would be able to collect from its associated LC pixel. The diffusion screen would be necessary to increase the display's viewing angle range due to the limiting numerical aperture of the microlens. The individual microlens would have a magnification set by the ratio of the overall size of the LCD module to its active area size, which for standard LCD modules (Figure 2a) is ~ 1.2. Figure 4 shows how the LC pixels are imaged onto the diffusion screen.

Major problems exist in this approach. The first problem concerns the image requirements of the microlens array. In Figure 4 only the central five pixels of the LCD module are pictured, and already the image of the edge of outer pixels is becoming aberrated. If one were to look at the requirements for the outermost LC pixel element microlens of the display, it would be required to redirect the pixel laterally 17.5 mm in a longitudinal distance of ~ 0.8 mm, causing the light beam to deflect 87 degrees. The 0.8 mm distance is set by the 1.2 magnification requirement. Figure 5 shows an outer element and its poor mapping of the LC pixel. The second major problem with this approach is the amount of crosstalk between adjoining pixels. The crosstalk is shown in Figure 6 for a single bundle of rays which fills adjacent microlenses and generates false images of the LC pixel. This crosstalk would be hard to reduce due to the use of a diffuse illumination source (light box) and to the presence of the cover glass between the LC pixel and the microlens .

To reduce the angular offset required by the outermost pixels one could increase the distance from the LC pixel to the microlens, thus increasing the image distance of the pixel while maintaining the 1.2x magnification requirement. This is shown in Figure 7. A central and edge pixel microlens pair are shown . The LC pixel -microlens distance in this case is 20mm and the microlens- diffusion screen distance is 15.5 mm. The central microlens maximum spatial frequency is ~30 lp/mm and the edge microlens maximum spatial frequency is ~ 1500 lp/mm. This outer microlens spatial frequency exceeds by an order of magnitude what has been manufactured for a diffractive focusing element.

A possible way of reducing the manufacturing requirements would be to split the function of the microlens array into two elements, the first imaging the LC pixel and the second deviating the angle of the beam. The first element would be a 640x 480 array of identical microlenses of maximum spatial frequency of ~30 lp/mm, well with manufacturing limits. The second array would be a set of linear gratings varying in spatial frequency and orientation with a spatial frequency of 0 at the center of the array increasing to ~1500 lp/mm at the edge. The fabrication of linear gratings with these high spatial frequencies may be possible. Splitting the functions of the microlens array up into two arrays allows one to reduce the crosstalk problem depicted in Figure 6 by using baffles between the two arrays as shown in Figure 8. The baffle would be similar to a microchannel plate with a light absorbent channel sides. The baffle is effectively making the illumination source for each LC pixel be a small source.

This implementation of our first design approach provides a physically manufacturable solution to the remapping of the LC pixel to allow for optical tiling of the displays. Two major problems still esixt, however: the low display brightness, and dispersion due to the high spatial frequencies of the grating array. The brightness loss is due to the microlenses working at very large f-numbers (~F/50) and causes a reduction in scene brightness by 2-3 orders of magnitude. The large incident angle of the edge mapped pixel at the diffusion screen will further reduce forward brightness. The grating array would be highly dispersive to the light incident on it. For an illumination waveband from 450 nm to 650 nm the maximum lateral remapping distance allowable using a linear grating must be less than 1mm for the chromatic spread to be less than one pixel width. A more monochromatic source or a bandpass filter would be required to eliminate the lateral spread of light at the diffusion screen and increase the lateral dimension of remapping. To achieve a 17 mm displacement would require a source with a waveband of ~2 nm at 550 nm. To reduce the larger amount of dispersion introduced by the diffracting gratings one could replace the with a refracting prism array as shown in Figure 9. This would allow a ~ 10 mm lateral offset. The method of fabricating an array of tiny prisms of varying direction and angle is hard to determine. The outer prism array elements would require a prism angle of ~35 degrees, which is a height change of greater than 200 μm across the 310 μm pixel. This would be extremely difficult to do with lithographic techniques due to the large etch depth required.

The second design solution is to use a microlens array on the substrate side of the LCD module and a negative lens on the cover glass side, as shown in Figure 10. The microlens array is used to focus light through the active area of the LC and form an image on a diffusion screen while the negative lens serves to remap the images to a larger size. In this approach the LC active area is effectively a shuttered window and not the imaged source as in the first approach. The imaged source in this case could be formed by a black matrix in front of the illumination light box. To eliminate crosstalk from adjacent pixels, the black matrix should be an array of channels. This approach would still have the brightness problems of the first approach but the use of a negative lens has eliminated the dispersion problem of the first approach. The negative lens would have to be a Fresnel lens to reduce its physical thickness at the edge and weight The resultant system is shown in Figure 11. This system would have ~ 5 percent barrel distortion. The fabrication of a traditional rotational symmetric Fresnel lens could be possible using diamond turning methods. However the rotational symmetry of this method prevents any anamorphic expansion for LCD modules whose active matrix area has a different aspect ratio than the physical outer edge.

A method to allow increase of the display brightness would be to make use of a collimated backlight source. This would reduce crosstalk problems and allow the microlens array to be located next to the LCD module output polarizer and immediately followed by the negative Fresnel lens and then the diffusion screen. A collimated backlight source would require a intense point source at the focal point of a collimating element. The focal length of the collimating element would be at least two times the width of the module, which would increase the displays longitudinal thickness and weight greatly.

3. SUMMARY

In our opinion, the only design approachusing the standard LCD module and light source which could reasonably be built is that of microlenses remapping the pixels onto a diffuser through a negative Fresnel lens (Figure 11). This method could tile together LCD modules separated by a maximum of 20 mm (10mm edge LCD module). The great drawback to this method is that in tiling together modules the illumination is less than 1 percent of the illumination of a stand-alone LCD module. Making use of a nonstandard (collimated) blacklight source would allow a increase of the illumination at the expense of final display size longitudinal thickness and weight.

4. REFERENCES

1. G.A. Alphonse and J. Lubin, "Psychophysical Requirements for Seamless Tiled Large-Screen Displays," Proc SID Vol XXIII (Digest of Technical Papers May 17-22, 1992), 941-4.

2. A. Abileah and Z. Yaniv, "Optically-tiled AMLCD for very large flat-panel display,"Proc. SPIE Vol 1664 (to appear1992).

3. A. Abileah and Z. Yaniv, "Optical Tiled AMLCD for Very Large Display Applications," Proc SID Vol XXIII (Digest of Technical Papers May 17-22, 1992), 945-9.

4. S. Kelly, "Removing the pixel structure from projected images using a transparent spatial filter," Proc. SPIE Vol 1664 (to appear1992).

5. G. Dolgoff, "Optical depixelization for electronic image projection,"Proc. SPIE Vol 1664 (to appear1992).

6. Joseph Scott, MagnaScreen Corporation, private communication (March, 1992).

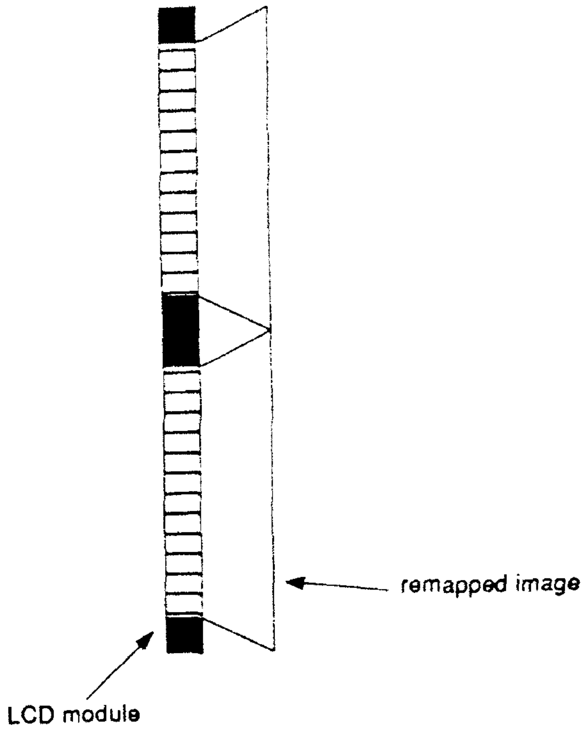
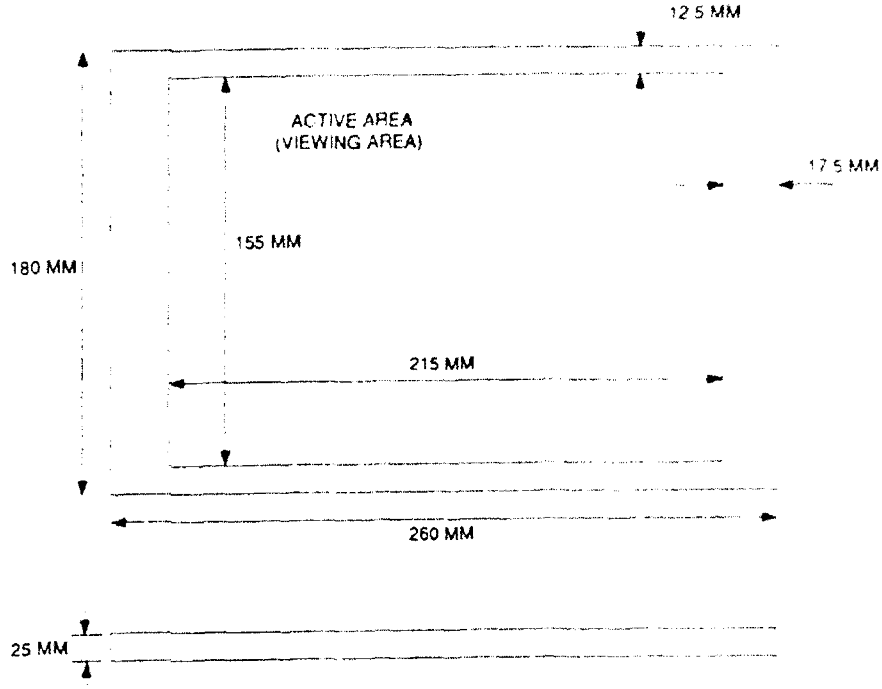


FIGURE 1. OPTICAL TILING CONCEPT



DISPLAY FORMAT	:	640 x 480 DOTS
DOT PITCH	:	.31 mm x .31 mm
DOT SIZE (ACTIVE AREA)	:	.28 mm x .28 mm

FIGURE 2 a. TYPICAL LCD MODULE

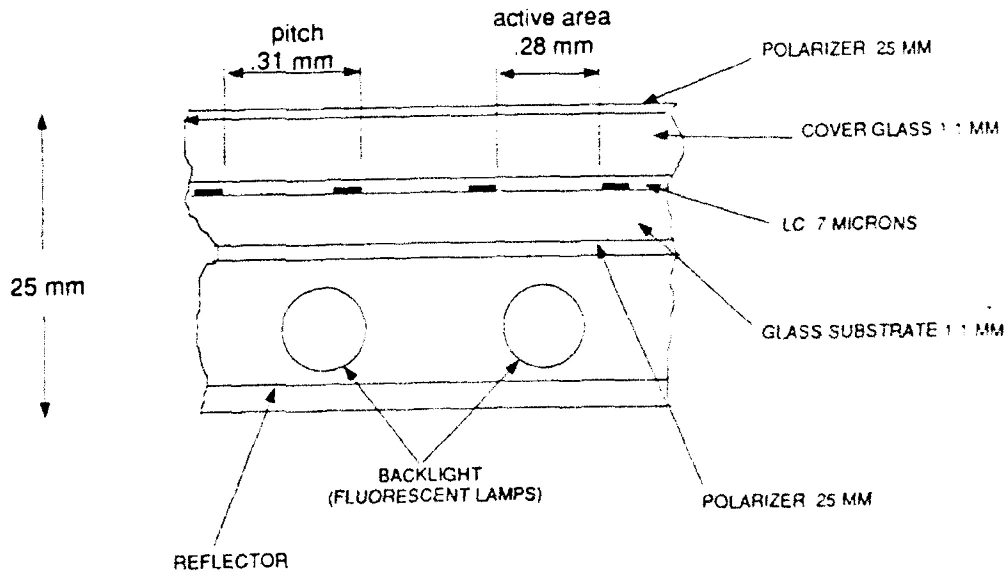


FIGURE 2b. LCD MODULE CROSS-SECTION

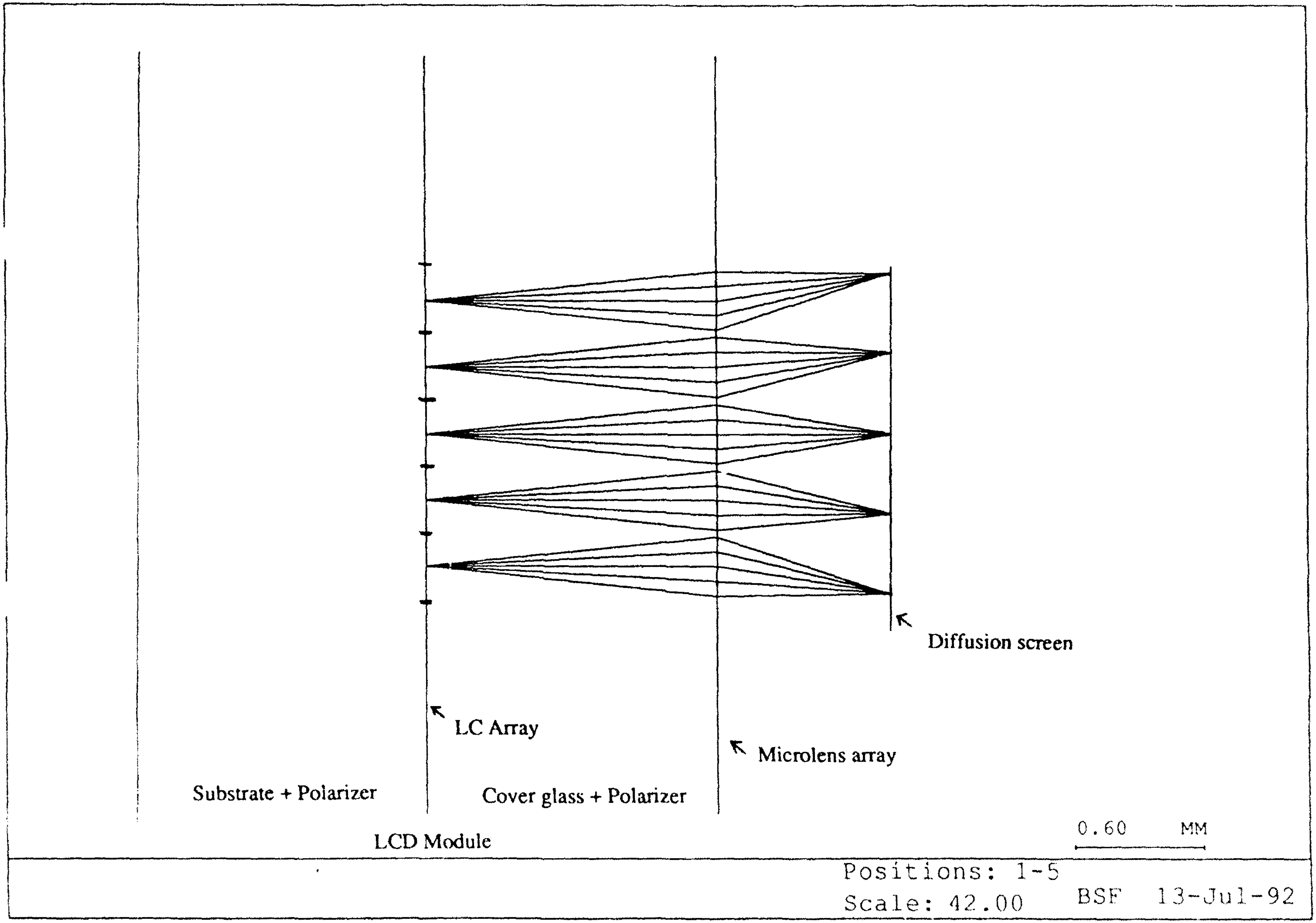
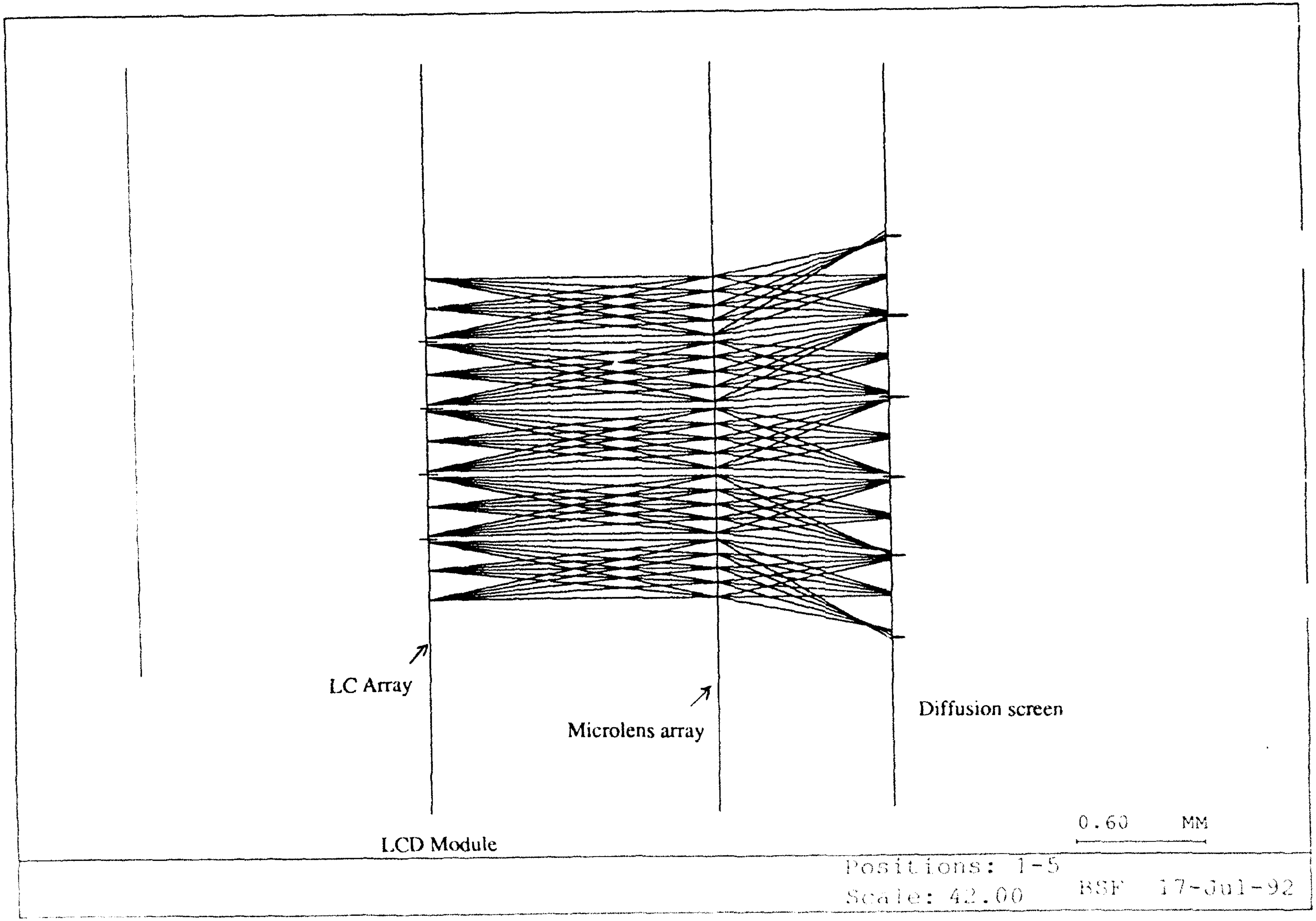


FIGURE 3. Microlens array next to output face of LCD module


LC Array
Microlens array
Diffusion screen
LCD Module
0.60 MM
Positions: 1-5
Scale: 42.00
BSF 17-Jul-92

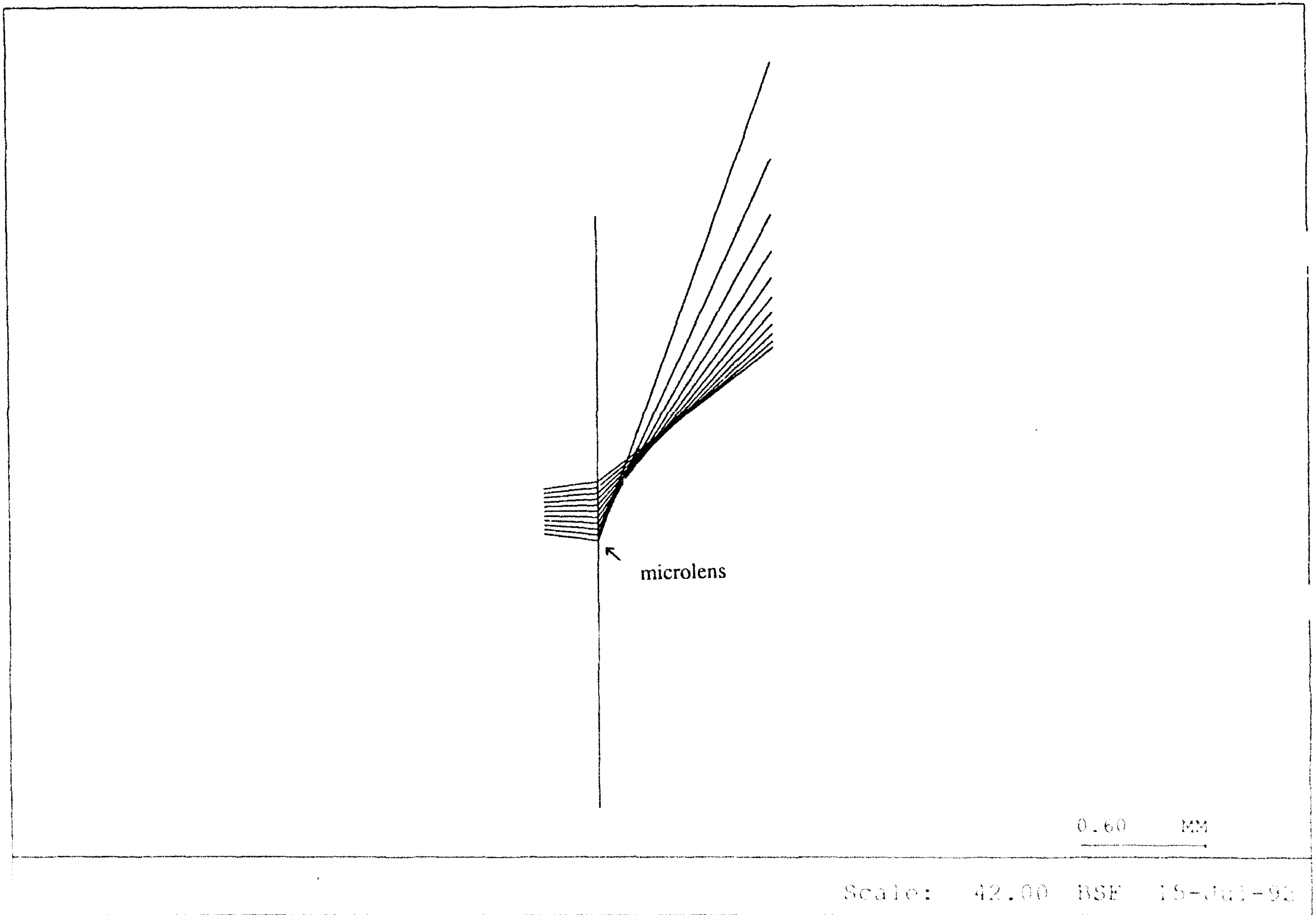
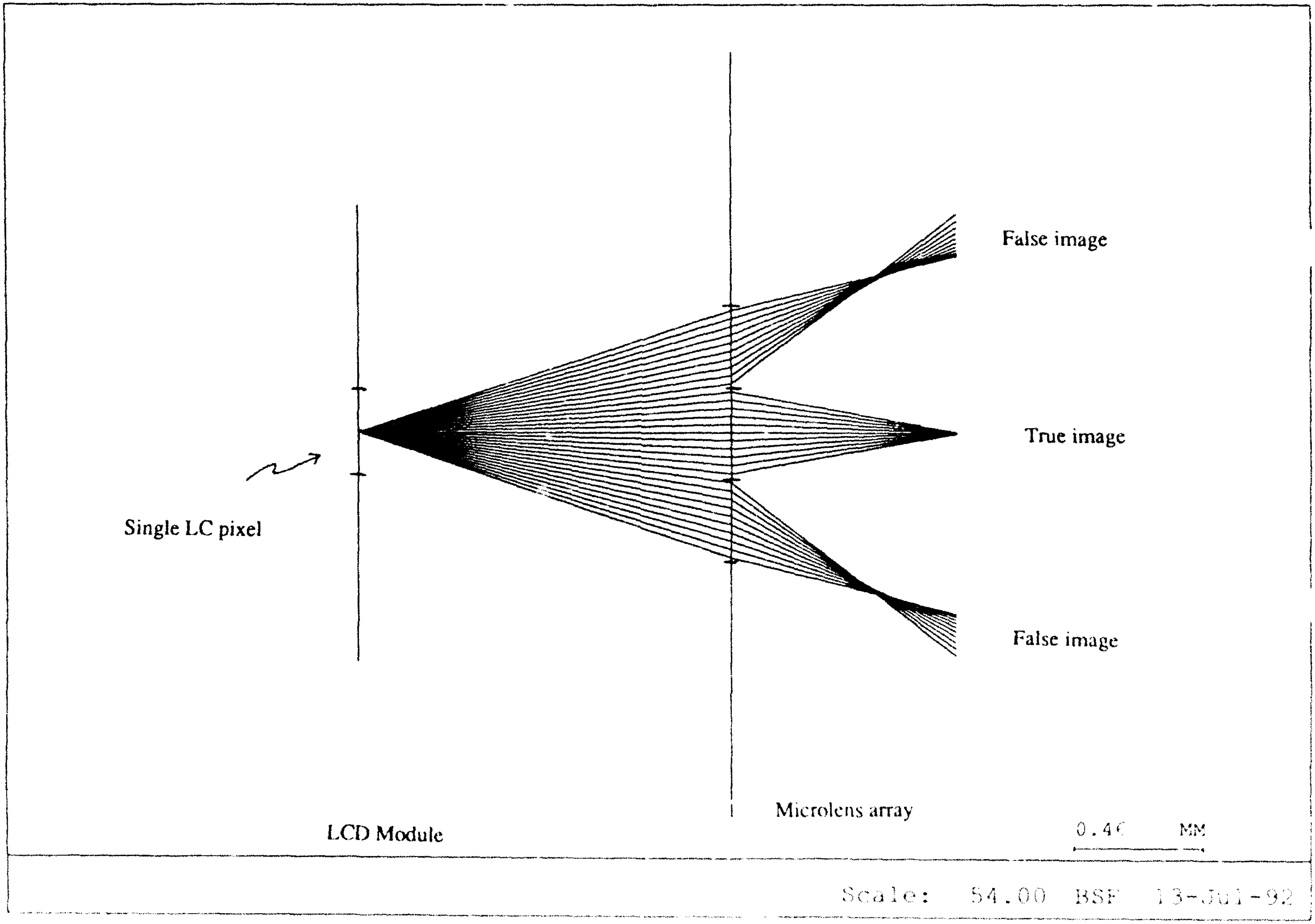
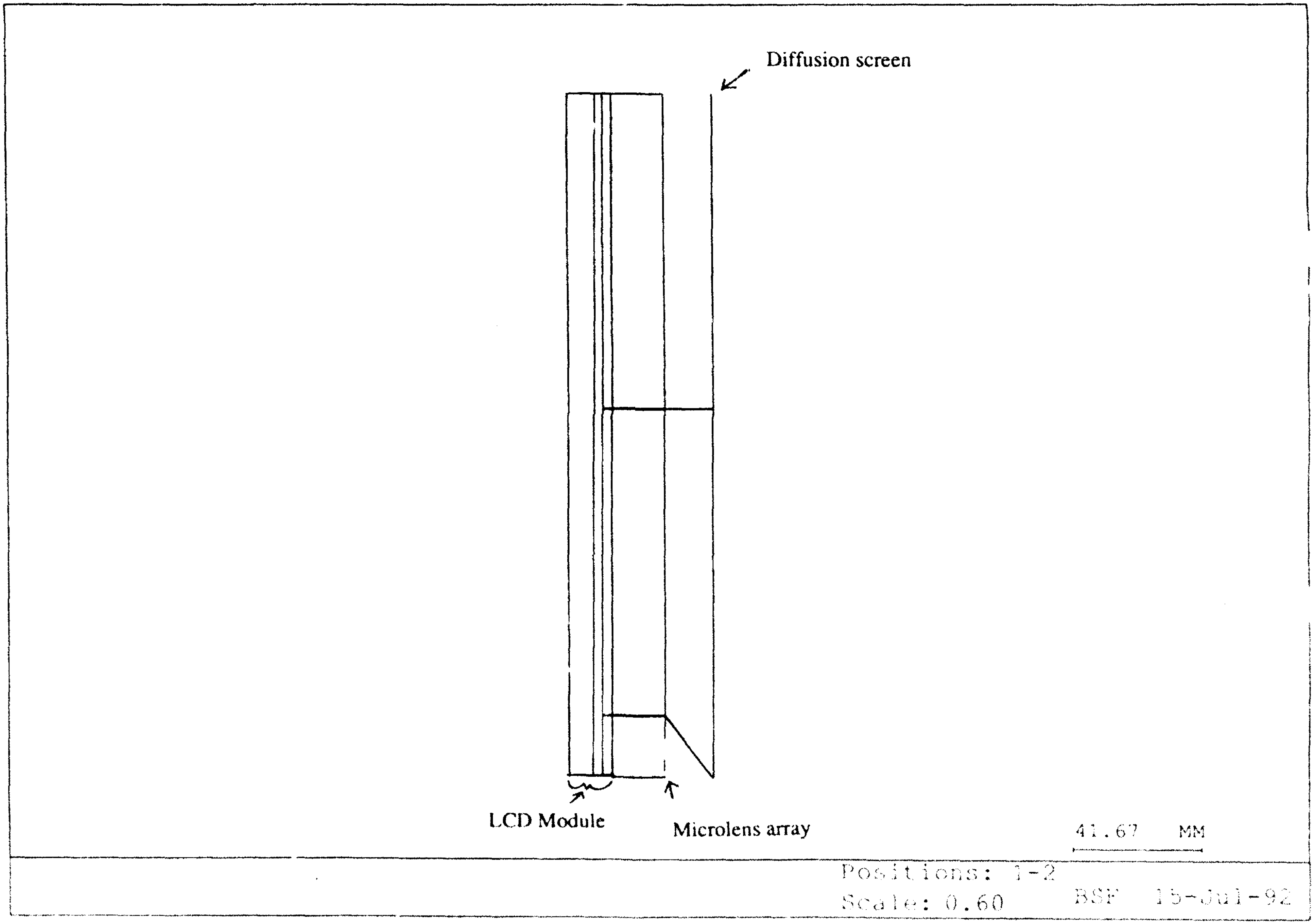
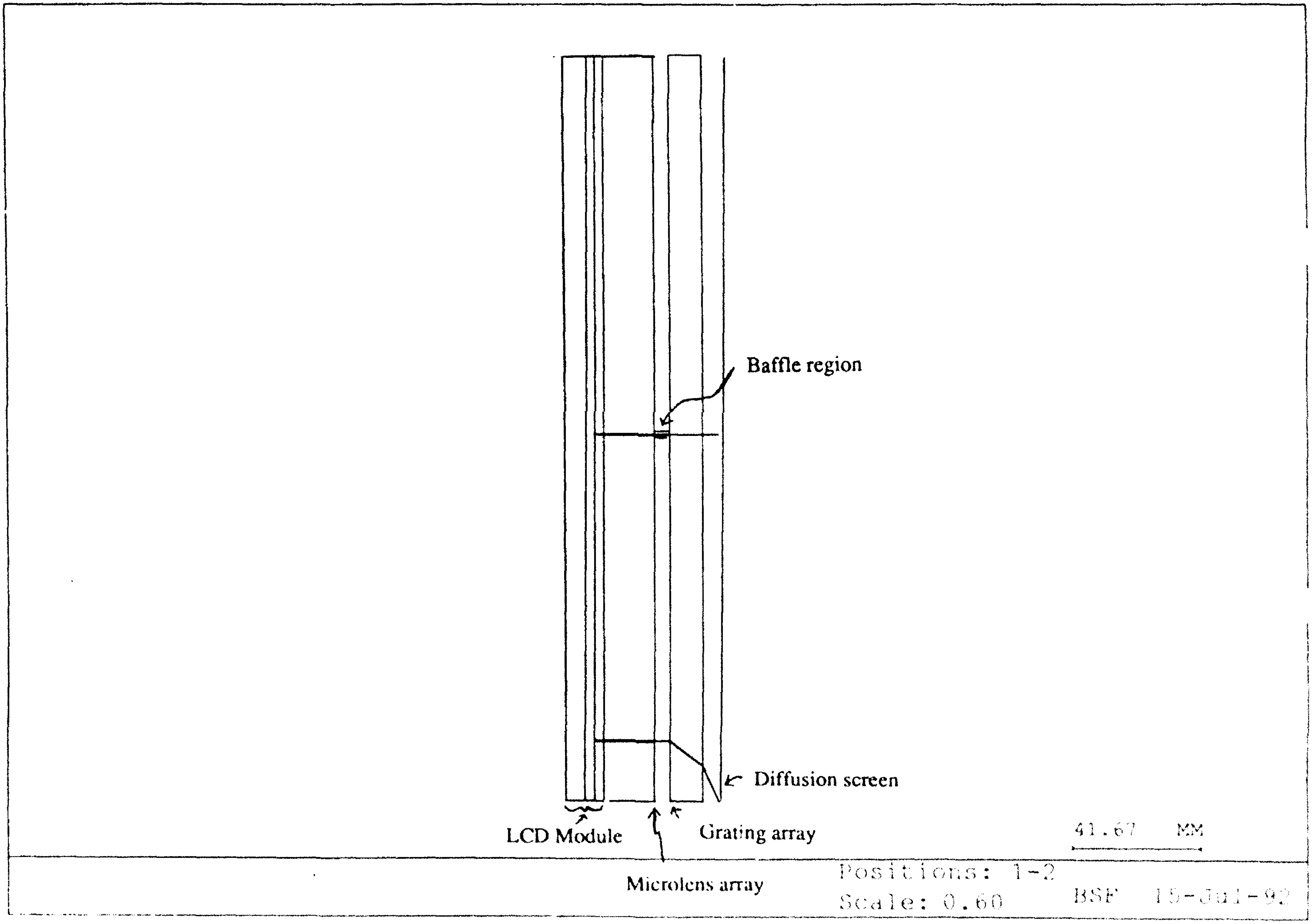


Figure 5 [illegible]


False image
True image
False image
Single LC pixel
LCD Module
Microlens array
MM
Scale: 54.00 BSF 13-Jul-92


Diffusion screen
LCD Module
Microlens array
41.67 MM
Positions: 1-2
Scale: 0.60
BSF 15-Jul-92



Baffle region
Diffusion screen
LCD Module
Grating array
Microlens array
41.67 MM
Positions: 1-2
Scale: 0.60
BSF 15-Jul-92

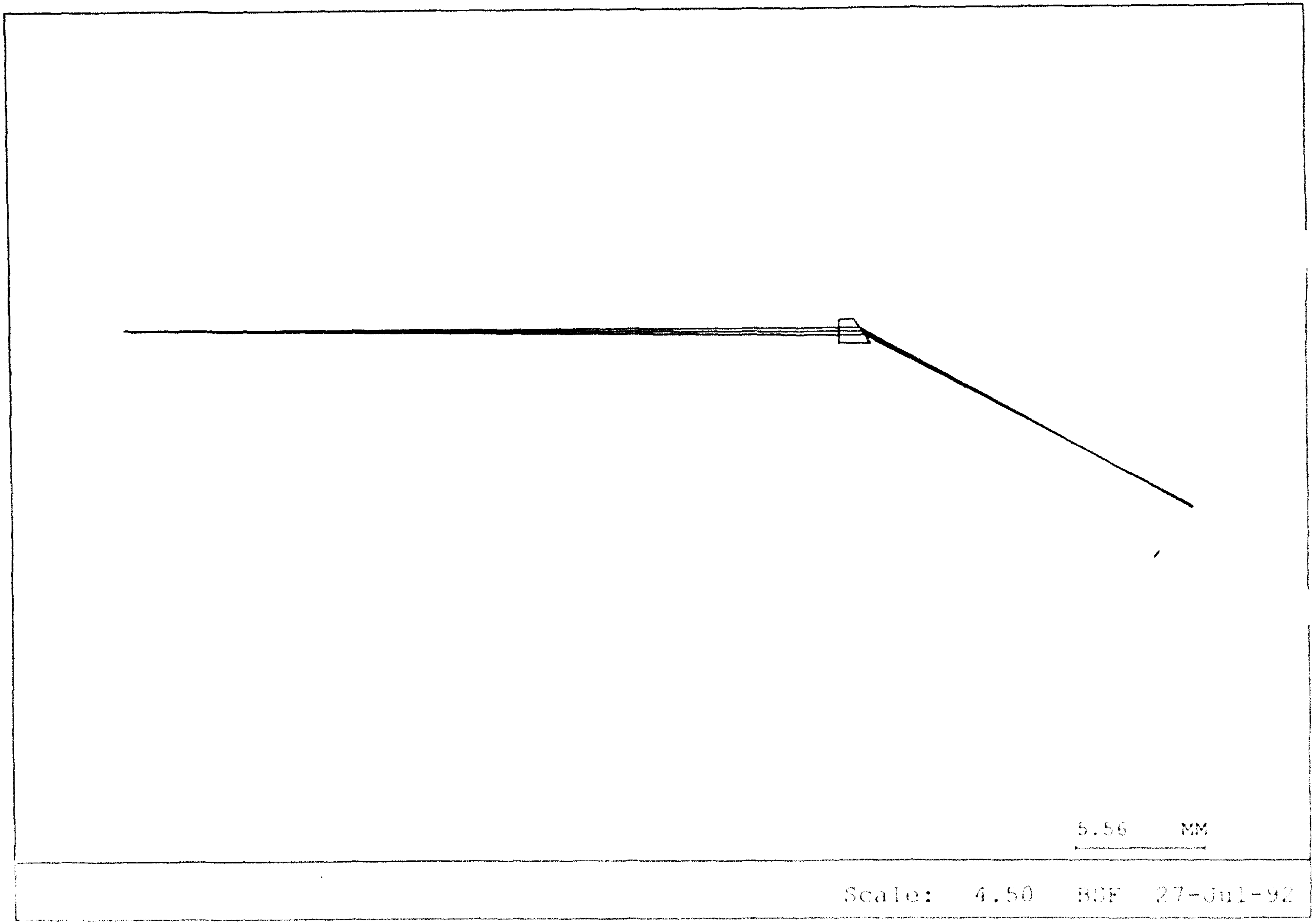


Figure 9. Refracting prism

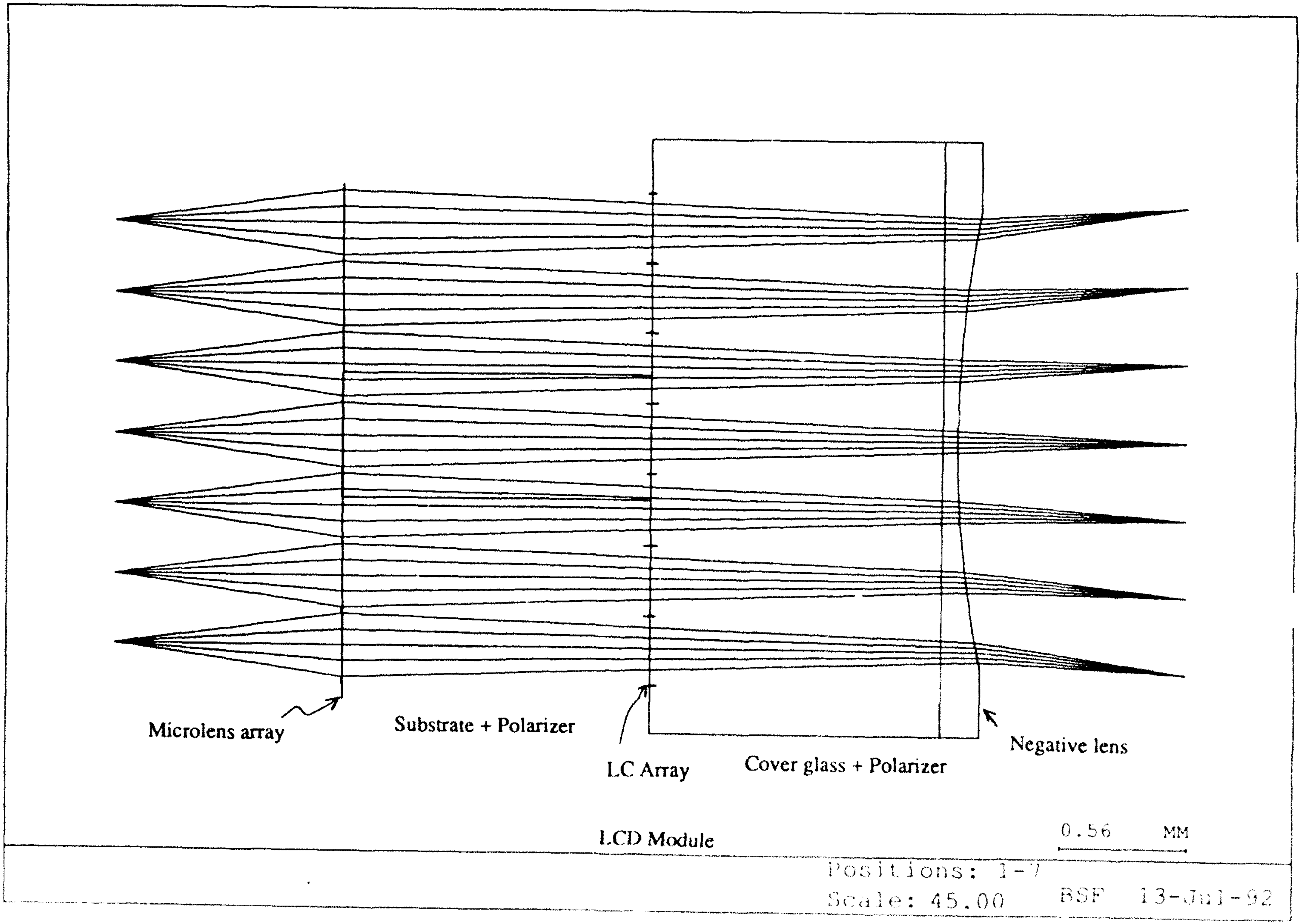


Figure 10. Microlens array with negative lens

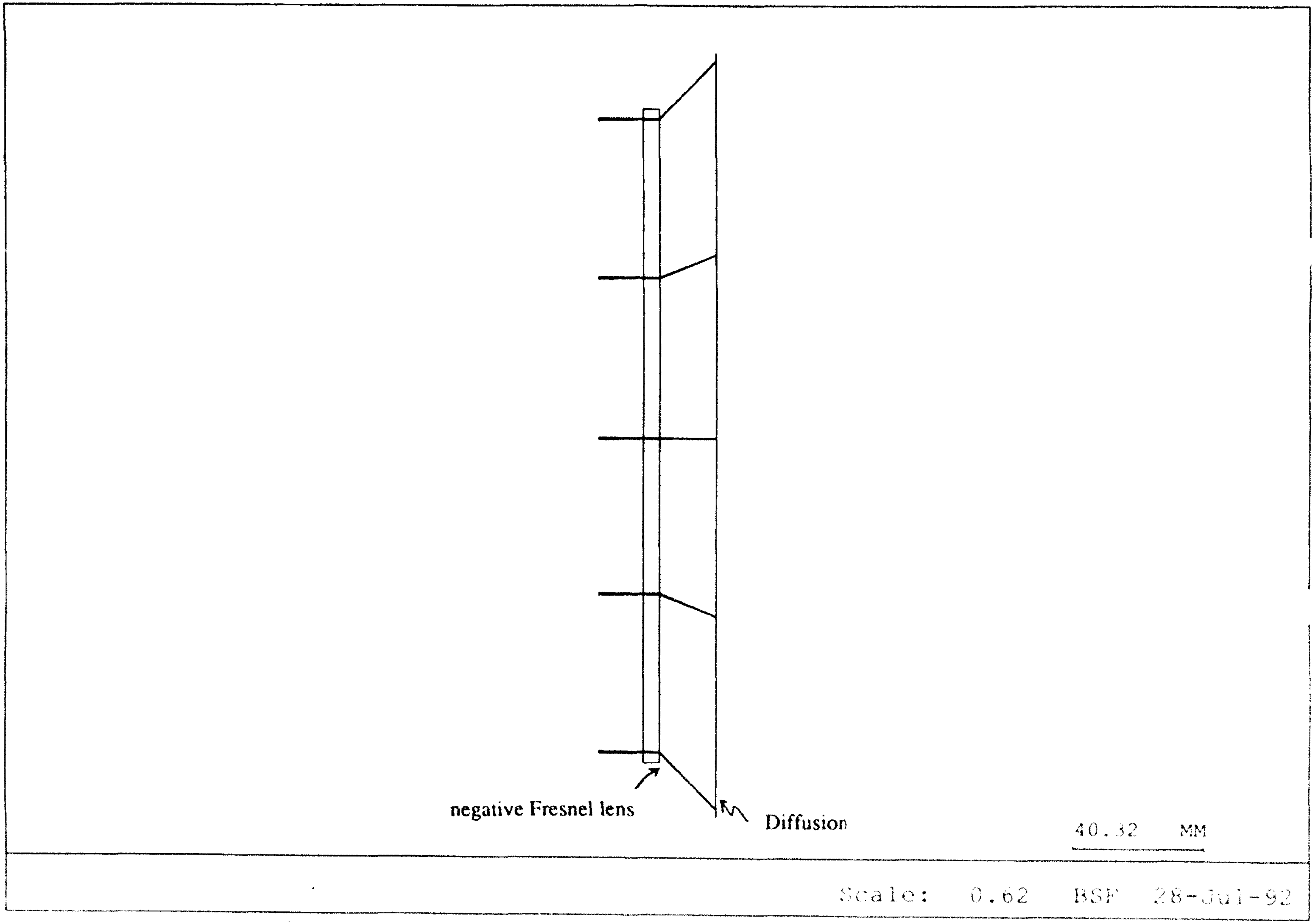


Figure 11. Microlens array with negative Fresnel lens